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THE RELATIVE PERFORMANCE OBTAINED WITH SEVERAL METHODS OF CONTROL OF AN OVERCOMPRESSED ENGINE USING GASOLINE

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SUMMARY

This report presents some results obtained at the Langley Memorial Aeronautical Labratory of the National Advisory Committee for Aeronautics, during an investigation to determine the relative performance characteristics for several methods of control of an overcompressed engine using gasoline and operating under sea-level conditions. For this work, a special single cylinder test engine, 5-inch bore by 7-inch stroke, and designed for ready adjustment of compression ratio, valve timing and valve lift while running, was used. This engine has been fully described in N. A. C. A. Technical Report No. 250.

Tests were made at an engine speed of 1,400 R. P. M. for compression ratios ranging from 4.0 to 7.6. The air-fuel ratios were on the rich side of the chemically correct mixture and were approximately those giving maximum power. When using plain domestic aviation gasoline, detonation was controlled to a constant, predetermined amount (audible), such as would be permissible for continuous operation, by (a) throttling the carburetor, (b) maintaining full throttle but greatly retarding the ignition, and (c) varying the timing of the inlet valve to reduce the effective compression ratio. For the first and third methods, the throttle opening and the valve timing, respectively, were adjusted so that the ignition timing could be advanced slightly beyond the advance giving maximum power without exceeding the standard of permissible detonation. The optimum performance for the engine when using a nondetonating fuel, consisting of 80 per cent of commercial benzol and 20 per cent of aviation gasoline, was obtained as a basis for comparison.

The following comparative results are based on the optimum performance for the engine obtained with the nondetonating fuel at a compression ratio of 4.7. The power and fuel consumption with method (b) remained substantially constant at the higher compression ratios, the order of the ignition timing permitting full throttle operation ranging from 30° at 4.7 to 3° at 7.3; exhaust temperatures, heat loss to the cooling water and explosion pressures at the higher ratios were normal. At a compression ratio of 7.5, the power obtained with method (a) was about 39 per cent less and the fuel consumption was considerably lower; with method (b), time of inlet-valve opening constant and time of inlet-valve closing varied, the power was about 23 per cent less and the fuel consumption was greatly increased; with method (c), time of inlet opening and closing varied simultaneously, the power was about 29 per cent less and the fuel consumption was greatly increased.

From these results, it may be concluded that method (b) gives the best all-round performance and, being easily employed in service, appears to be the most practicable method for controlling an overcompressed engine using gasoline at low altitudes.

INTRODUCTION

Owing to the inherent advantages of higher specific output and reduced fuel consumption resulting therefrom, considerable attention has been directed toward increasing the expansion ratio of the carbureted engine, particularly the engines used in aircraft, as it is in this field that the above advantages are in greatest demand. However, coincidentally with an increase in the expansion ratio, there is, in conventional engines, a corresponding increase in the compression ratio with consequent aggravation of those conditions within the engine inducing detonation and preignition. For this reason, compression ratios have been limited by the detonation characteristics of the fuels available for general service use and, where higher compressions have been employed, it has been necessary to resort to the use of special fuels, which have not been, and are not now, at once cheap and generally available. Thus, the employment of higher compression ratios in aircraft engines has not been generally adopted.

However, as conditions inducing detonation in the high-compression engine become less severe at high altitudes, a compromise has been sought, in which relatively high-compression ratios are employed in conjunction with throttling at low altitudes to reduce the density of the charge and thus suppress detonation until sufficient altitude has been gained to permit full-throttle operation. This scheme has received approval because it permits the use of fuels that are generally available, results in increased fuel economy (greater expansion ratio) at all altitudes, and gives an altitude range of constant power output. For operation below the altitude permitting full-throttle operation, the maximum permissible output, compared to the maximum obtainable with the same engine using a nondetonating fuel, is considerably reduced, and the specific weight of the engine, even when designed especially for the reduced stresses accompanying the reduced power, is increased. Thus, the questions arise: How much throttling is required to suppress detonation at low altitudes, does the performance under this condition compare favorably with that of a normal engine permitting full-throttle operation with the common fuel, and is this method of control, by throttling, the most advantageous? In this connection, Ricardo has shown (Reference 1) that the specific output of an overcompressed engine throttled to prevent detonation is relatively low. But information showing the relative performance obtained with other methods of control is, apparently, not available.

The present investigation was undertaken, therefore, at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics in connection with a research program involving the determination of the comparative flight performance of normal, overcompressed, and supercharged engines. The immediate object was to determine the relative performance of a single-cylinder, four-stroke-cycle, high-compression engine using domestic aviation gasoline with detonation controlled to a constant, predetermined, and permissible amount by throttling, retarding the ignition timing and varying the inlet valve timing. The full-throttle performance for optimum conditions when using a nondetonating fuel consisting of 80 per cent of commercial benzol and 20 per cent aviation gasoline was also obtained for comparison. The range of compression ratios used was from 4.0 to 7.6.

The tests herein reported were conducted under the immediate supervision of Clyde R. Paton.

DESCRIPTION

For the present investigation a special, single-cylinder, four-stroke-cycle test engine, 5-inch bore and 7-inch stroke, connected to a 40/100 HP. electric cradle dynamometer was used. This engine, a transverse cross section of which is shown in Figure 1, has been fully described in Reference 2. Briefly, the following adjustments can be made while the engine is running: A change in compression ratio from 4 to 14; a variation in the time of opening and closing of both the inlet and exhaust valves of 50° measured in terms of crank travel, the opening and closing being controlled independently, and a variation in the lift of both the inlet and exhaust valves from ¼ inch to ½ inch. Overhead valves are used, the two inlet and the two exhaust valves being operated by independent cam shafts. The water jackets for the cylinder head and cylinder barrel are separate, so that the temperature of the cooling water for each may be controlled independently. For the present tests the compression ratio was varied from 4 to 7.5, and for all tests except those involving a varied timing the following valve adjustments were used:

Inlet open	10 degrees after top center.
Inlet closed	45 degrees after bottom center.
Inlet-valve lift	$\frac{7}{16}$ inch.
Exhaust open	50 degrees before bottom center.
Exhaust closed	10 degrees after top center.
Exhaust-valve lift	⅜ inch.

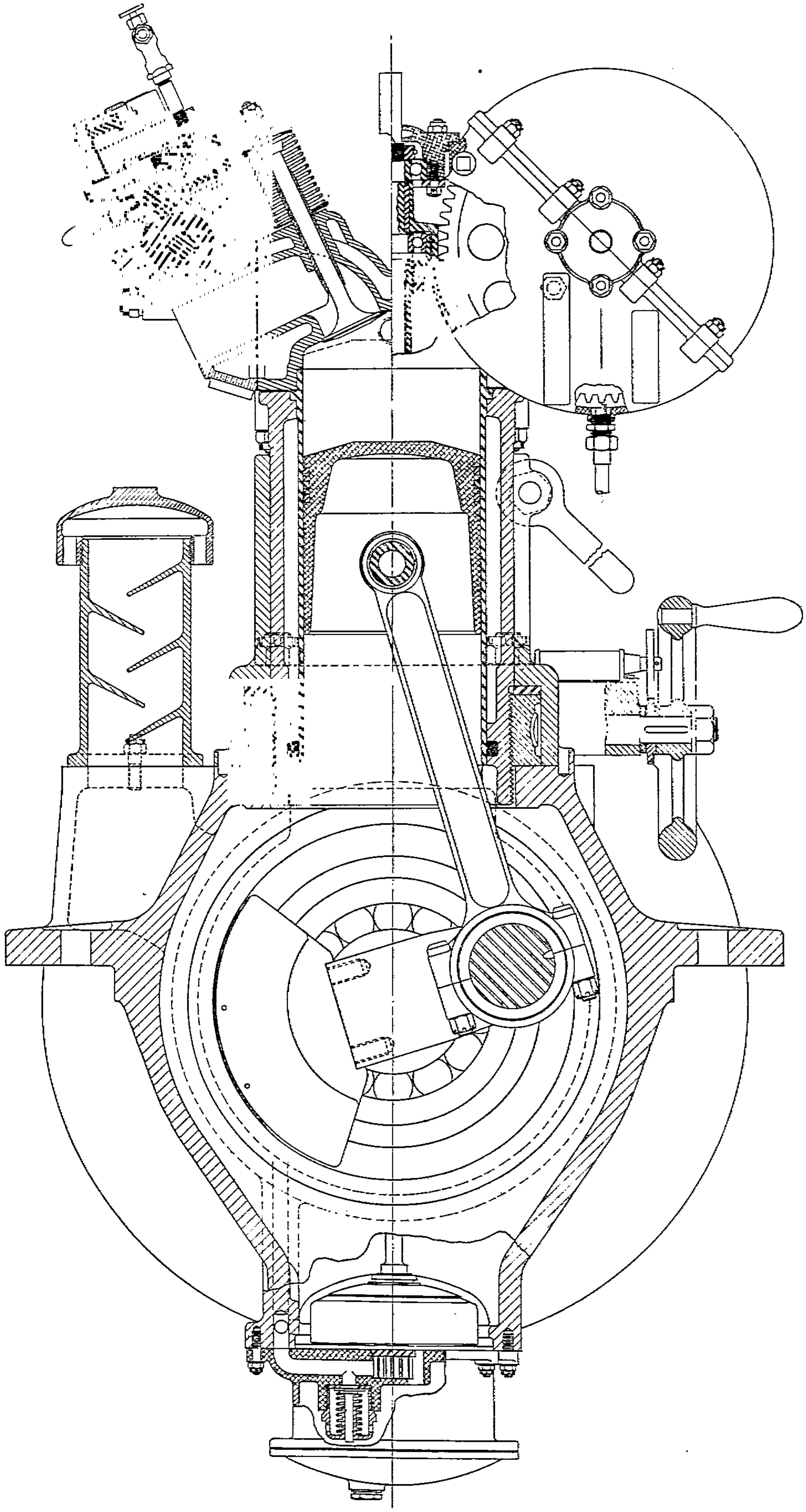

FIG. 1.—Transverse section through single-cylinder test engine, showing adjustment for varying the compression ratio while running

For the tests with constant inlet-valve opening and late closing, the latter was varied from 45° to 108° after bottom center. For the tests with the total inlet phase displaced in the cycle, the phase was maintained at 125° and the time of opening varied from 10° to 60° after top center.

Two porcelain-insulated spark plugs located diametrically opposite on the longitudinal axis of the cylinder were used; these were timed synchronously.

A standard Liberty engine duplex carburetor was used, one Venturi being completely closed and the main metering jet for the remaining Venturi being provided with a needle valve for ready adjustment of the fuel flow. Some tests were made with a small fixed metering jet, the needle valve being omitted.

Fuel consumption was measured by timing the rate of flow from a 400 cm.³ tank.

Domestic aviation gasoline, conforming to Army specifications, was used as the detonating fuel. A mixture of 80 per cent of benzol (commercial 90 per cent) and 20 per cent aviation gasoline (80–20 blend) was used as the nondetonating fuel.

A diagrammatic layout of the induction system is shown on Figure 2. Air measurements were made with a gasometer having a displacement volume of 10 cubic feet; the gasometer bell

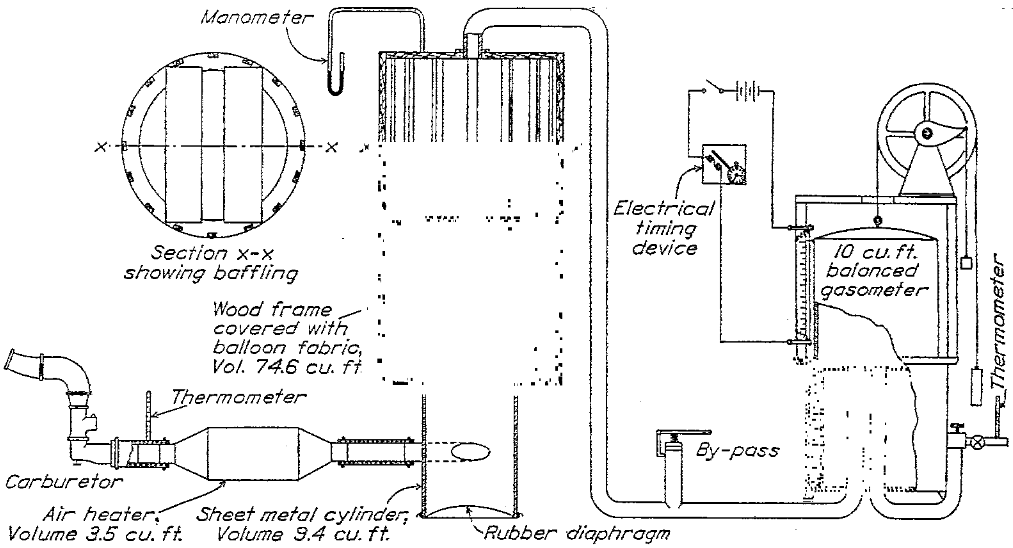

FIG. 2.—Diagrammatic layout of induction system used with single-cylinder test engine, showing the gasometer with the moving bell counterbalanced for weight and flotation, the large receiver, and the electric heater for temperature regulation

was counterbalanced for weight and flotation. Time was measured by a stop watch operated through an electric relay and contacts located on the gasometer bell. The pulsating flow was damped by providing a large-volume receiver between the gasometer and engine. An air heater, located between the receiver and carburetor, was used for temperature regulation.

Engine speed was measured with a revolution counter and stop watch, both operated synchronously by means of an electric switch. Torque was measured on a platform scale.

Exhaust temperatures were measured with a thermocouple and an indicating pyrometer. All other temperatures were measured with mercury thermometers. The following temperatures were maintained practically constant by manual control:

	° F.
Water in	140
Water out of cylinder head	180
Water out of cylinder barrel	170
Oil out	130
Air to carburetor	95

A spring-loaded piston element proved unsatisfactory for measurement of combustion-chamber pressures, and this was replaced with a maximum-pressure gauge unit, in which the chamber pressures acting on the under side of a ⅛ inch steel ball-check-valve were balanced by gas pressure introduced on the upper side from a storage tank. An indicating gauge was in direct communication with the space above the check valve. The method of operation consisted in adjusting the gas pressure in the valve chamber, by means of an admission and a bleeder valve, to the point where the gauge needle ceased vibrating. Compression pressures were measured in the same manner.

In adjusting the engine settings to give a constant, predetermined, and permissible amount of detonation, several instruments for measuring the amount of detonation were tried but found unsatisfactory. During this preliminary testing, it was found that the amount of detonation obtaining under given conditions could be more readily and more accurately determined by the ear of an experienced observer, so that, for the tests herein reported, an arbitrary standard of audible detonation was determined upon as the criterion in adjusting the engine. In order to minimize errors due to the personal factor, two experienced observers checked each other in estimating that the amount of detonation existing during any particular run was in accordance with the standard.

METHODS OF TESTING

The tests herein reported were made at a constant engine speed of 1,400 R. P. M., although, in some cases, additional tests were made at 1,200 and 1,600 R. P. M. to check the general trend of the data obtained at the intermediate speed. For any given test, after conditions were stabilized, a power run was made extending over a time interval averaging from two to three minutes, during which readings were taken of engine speed, torque scale, rate of fuel and air consumption, exhaust temperatures, and explosion pressures, and the water from both the cylinder head and cylinder barrel diverted into containers and weighed for the determination of heat dissipation to the cooling water. Immediately following each power run, and for the same engine settings used during the power run, the circulation of cooling water was shut off and a friction run was made by motoring the engine with the dynamometer. Compression pressures were measured during these friction runs.

The testing methods employed with the several schemes of operation are thought to be of sufficient interest to merit a detailed description:

1. Effect of ignition advance on the performance of a high-compression engine when using (*a*) a detonating fuel and (*b*) a nondetonating fuel (fig. 3): In this case, the compression ratio was fixed arbitrarily at 6.3, the carburetor needle-valve was maintained at a constant setting, and full-throttle performance obtained at progressively increasing ignition advances ranging from top center to 50° advance.

2. Optimum performance with a nondetonating fuel: Full-throttle performance was obtained for the range of compression ratios from 4 to 7.3. At each compression ratio, the ignition setting and air-fuel ratio were adjusted to give maximum power.

3. Throttled performance using a detonating fuel:

   (*a*) With a fixed ignition advance: In these tests, the ignition advance was fixed arbitrarily, the air-fuel ratio was adjusted for each run to an approximately constant value of 12.2. Full-throttle runs were made at low compression ratios, and, as the compression ratio was increased, the throttle was adjusted to give the standard of detonation.

   (*b*) Throttled performance with normal optimum ignition advance: In these tests, the arbitrary criterion for the permissible amount of throttle opening selected was the greatest opening that permitted the ignition to be advanced slightly beyond the advance giving maximum power without exceeding the standard of detonation. At a given compression ratio, the throttle opening was fixed arbitrarily and several preliminary runs made at increasing ignition advances until the standard of detonation was obtained; the throttle was reset at a lesser opening and preliminary runs made as above, until the arbitrary condition had been fulfilled, following which a run was taken for this throttle opening and the optimum ignition advance. Tests for compression ratios from 4.5 to 7.5 were made with a fixed carburetor jet giving an approximate air-fuel ratio of 12.2.

4. Full-throttle performance with greatly retarded ignition: In these tests, full throttle was maintained and the ignition timing was retarded sufficiently to give the standard of detonation at compression ratios of 5.3, 6.3, and 7.3. The air-fuel mixture was adjusted to give approximately maximum power.

5. Full-throttle performance with varied timing for the inlet valve: Tests were made with fixed carburetor metering jets giving an approximate air-fuel ratio of 12.2. For a given compression ratio, the valve timing was set arbitrarily and the ignition adjusted to give the standard of detonation; the valve timing was readjusted and the ignition advance varied until a valve timing was determined that permitted the ignition timing to be advanced slightly ahead of the advance giving maximum power without exceeding the standard of detonation. A run was then made for the valve timing so determined and with the optimum ignition advance. Two methods of varying the inlet valve timing were used:

(*a*) With the time of opening fixed, and the time of closing varied; range of compression ratios from 6 to 7.5.

(*b*) With the time of opening and closing varied simultaneously; range of compression ratios from 5.1 to 7.6.

PRECISION

Changes in atmospheric conditions caused relatively large variations in the amount of detonation, as evidenced, for instance, by the fact that, for otherwise constant engine conditions, the amount of throttle opening permissible without exceeding the standard of detonation varied somewhat on successive days. This caused some discrepancies in the engine settings necessary to fulfill given requirements, and introduced unknown errors in the comparative results. As these variations affected the results probably to a greater extent than any instrumental or personal errors, a discussion of the latter is thought to be unnecessary.

For the above reason, precise comparisons of the relative performances can not be made. However, the data are sufficiently precise to permit of making some general comparisons.

RESULTS

The results are presented in the form of curves on Figures 3 and 4, the comparative performance being presented as plots on a percentage basis for ready comparison. The base values are for the optimum performance of the engine using a nondetonating fuel at a compression ratio of 4.7 to 1; these base values are given on the several curves. Power has been corrected to a standard pressure of 29.92 inches mercury. Some comparative results taken from Reference 1 are also shown.

DISCUSSION

For the reason that some detonation is permissible, and that maximum power for a given fuel is usually obtained when a small amount of detonation is present, a criterion of "some" detonation rather than "no perceptible" detonation was selected. Moreover, many service engines are operated under such conditions; that is, with a certain permissible amount of detonation present during full-throttle operation. The amount of detonation selected as permissible in the present tests had no perceptible effect on power or heat losses to the cooling water, and was such as would be permissible in an engine for continuous operation.

Preliminary tests with gasoline at a compression ratio of 7.3 to 1 showed that, for a given ignition advance, the amount of throttling required to limit detonation to the permissible amount was dependent to a great extent on the quality of the fuel mixture. In one test at a compression ratio of 7.3, increasing the air-fuel ratio from 14.7 to 17.4, with a fixed ignition advance of 30°, permitted a greater throttle opening and resulted in an increase in power of more than 14 per cent. On the lean side, the mixture permitting the greatest throttle opening, and consequently giving maximum power, varied considerably with a change in ignition advance; for one test, at a compression ratio of 7.3, the air-fuel ratio giving maximum power changed from 15.8 to 18.7 for a change in ignition adavnce from 5° to 20°. The range of air-fuel ratios giving maximum power on the rich side also varied with the ignition advance but, in general, it was found that these ratios ranged from 11.7 to 12.3 for all compression ratios. For the results presented herein, the air-fuel ratios were approximately those giving maximum power on the rich side, thus simulating, approximately, flight service conditions. However, some variations in these ratios have entered to influence the results, and to prevent obtaining precise comparisons.

The information given in Figure 3 is presented to indicate the effect of ignition advance on engine performance at a compression ratio of 6.3 when operating at full throttle with plain aviation gasoline, and with a nondetonating fuel. The carburetor needle-valve adjustment was slightly different for the two fuels, but was maintained constant for each fuel; these settings

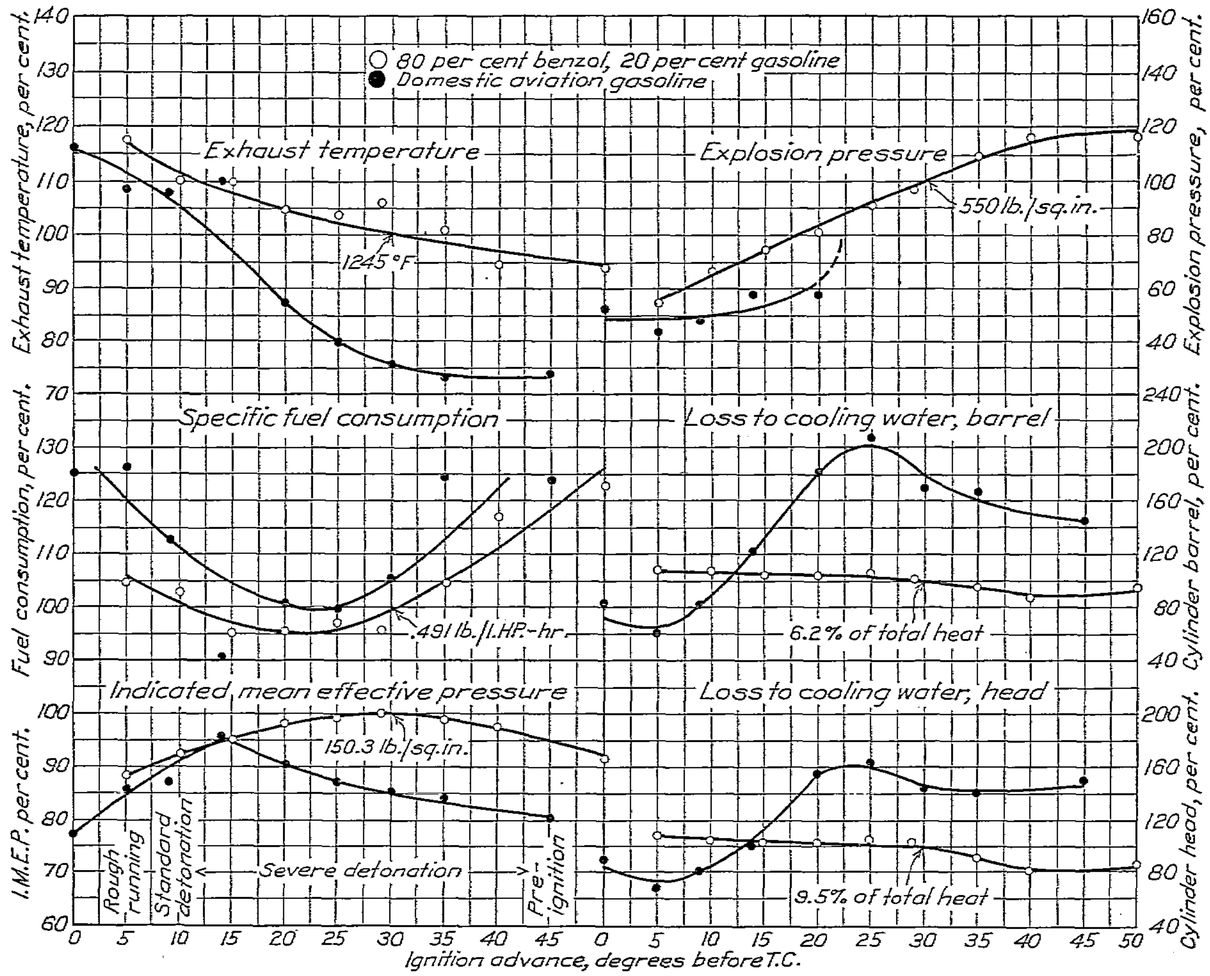

FIG. 3.—Effect of ignition advance on engine performance at a constant speed of 1,400 R. P. M. and a constant compression ratio of 6.3:1 when using gasoline and a nondetonating fuel. Percentages are based on values obtained with the nondetonating fuel for optimum power at 30° ignition advance. These base values are noted on the several curves. The notes on detonation refer to operation with gasoline

did not necessarily give maximum power. There were wide variations (from 12 to 13.5 for gasoline and from 10 to 12.5 for the 80–20 blend), in the air-fuel ratios, which caused some irregularities in performance. From these data, it is seen that, when using gasoline, there is a marked increase in the severity of detonation as the ignition timing is advanced beyond 10°, resulting finally, for an advance of 45°, in excessive preignition and fused spark-plug electrodes. Under these severe detonation conditions, there is a marked decrease in power and an increase in the heat losses to the cooling water. When using the 80–20 blend, there is a normal reduction in power for ignition advances beyond the optimum of 30°, but the heat losses remain fairly constant, or even decrease slightly, and the explosion pressures increase uniformly. Attention is called to the fact that maximum power with gasoline was obtained at an advance slightly greater than the advance giving the arbitrary standard of detonation; also, that the extreme detonation did not tend to increase the exhaust temperatures. The explosion pressures when using gasoline increased rapidly for ignition advances above 20°. Although the maximum-pressure gage was not reliable for measurements under these conditions, the indication was that pressures of the order of 1,600 pounds per square inch existed. For the range of ignition timing resulting in severe detonation, there was probably some power lost as negative work on the piston due to incipient preignition. The power runs in this region were maintained only for a period of about two minutes. From these results, it is apparent that full-throttle operation with gasoline at this compression ratio could not be maintained continuously for ignition advances greater than 9–10°.

The optimum performance when using the 80–20 blend and the comparative performance obtained by the serveral methods of control when using gasoline are shown on Figure 4. The performance curves are numbered in accordance with the test conditions enumerated in the title for this figure.

Considering the optimum performance of the engine using the 80–20 blend, it is found that the variation in indicated power and indicated specific fuel consumption with change in compression ratio is approximately that given by the ratio of air-cycle efficiencies. There is an indication that power increases with compression ratio at a faster rate than given by the cycle efficiencies, but this slight discrepancy may be attributed to small errors introduced by the method of obtaining friction power. It is seen that the optimum ignition advance decreases slightly with increase in compression ratio, a decrease from 37° to 26° being noted for a change in compression ratio from 4 to 7.3. The observed optimum air-fuel ratios for the different compression ratios varied (from 11 to 12.5) more than would be expected, but, as the direction was not consistent and as power was not very sensitive to changes of mixture in this range, an average value of 12 may be considered as representing the optimum for all ratios. In this connection it should be kept in mind that the chemically correct air-fuel ratio for this fuel is less than for gasoline. The variations in air-fuel ratios have caused some irregularities in the observed values for specific fuel consumption.

Tests made with gasoline at a fixed ignition advance and throttling to suppress detonation will next be considered. In this case it was found that, for a fixed advance of 30°, full-throttle operation could be maintained up to a compression ratio of 4.7 without exceeding the standard of detonation, but that at the higher ratios considerable throttling was necessary, with a resultant sharp decrease in power. Values for power at the higher ratios were obtained from cross plots, and no data points are shown. For an advance of 24° full throttle could be maintained up to a compression ratio of 5, and for 18.5°, up to 5.3. For these lower advances the full-throttle power at the lower compression ratios was reduced, as the timing used was less than the optimum, but at the higher ratios the permissible power increased as the timing was retarded. This comparison points clearly to the sensitiveness of ignition timing in its influence on detonation, and hence to the amount of throttling necessary and the permissible power output at the higher ratios.

The above discussion leads logically to a consideration of the results obtained when the ignition timing was retarded sufficiently to permit full-throttle operation at all compression ratios investigated. From the above discussion it was seen that permissible power increased with decrease in ignition timing at the higher ratios. Thus it would be expected that maximum power at these ratios would be obtained by carrying this procedure to the limit. Such was found to be the case, and of those methods investigated retarding the ignition timing to permit full-throttle operation proved to be the most advantageous from the standpoint of power. With this method of control, the permissible power remained substantially constant for all ratios from 4.7 to 7.3, whereas for the other methods the power decreased at the higher ratios. It is noted that the power obtained by this method at the intermediate ratios approximates that obtained by Ricardo (Reference 1, p. 92) when admitting cooled exhaust gases with the intake charge to suppress detonation in an overcompressed engine using fuel having a low toluene value. (Fig. 4.) Fuel consumption with retarded ignition was not excessive, but remained practically constant at the value of 0.532 pound per I.HP. per hour, obtained with the non-detonating fuel at a compression ratio 4.7. Heat losses to the cooling water and the exhaust temperatures also remained normal. The ignition advance found necessary to give these

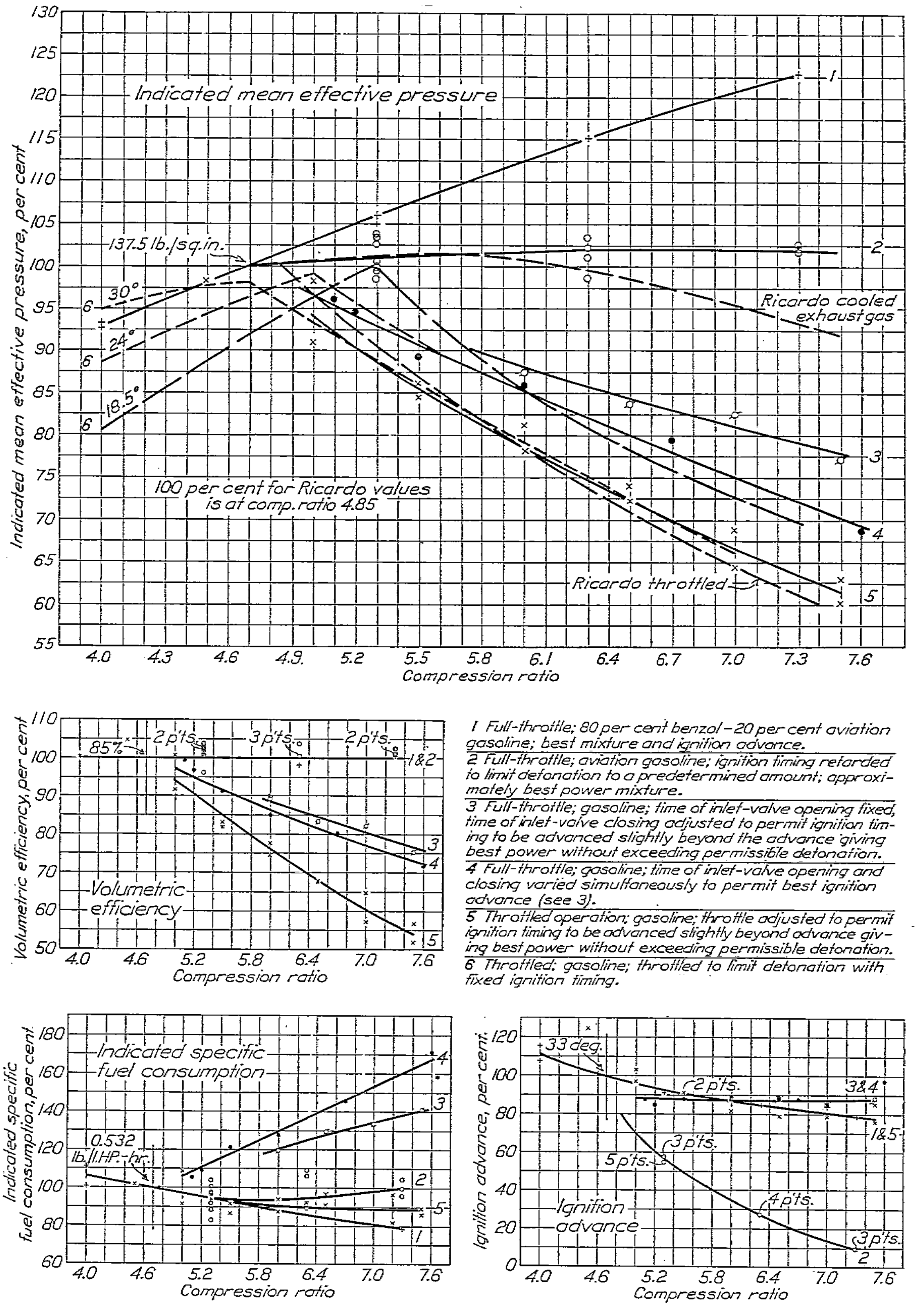

FIG. 4.—Comparative performance obtained with several methods of control of an overcompressed engine. Performances shown as percentages based on values obtained with a nondetonating fuel at a compression ratio of 4.7. Base values are shown on the various curves. The curves are numbered to correspond to the conditions of operation as given

results varied from 30° at 4.7 to 3° at 7.3 compression ratio. Ignition timing at the higher ratios was very critical, small changes in timing causing considerable variation in the amount of detonation. This is probably the greatest disadvantage of this method for service use. The present tests do not show to what extent the compression ratio may be increased with this method of control, but apparently this method may be used advantageously up to a compression ratio of at least 8:1.

The performance obtained when throttling the carburetor just sufficiently to permit the ignition timing to be advanced, for each compression ratio, slightly beyond the advance giving maximum power will next be considered. The condition stipulated in these tests is, admittedly, an arbitrary one, but it fulfills, in general, the service condition where the ignition advance at low altitudes is maintained constant at the adjustment giving maximum performance for altitudes above that permitting full-throttle operation. It may be seen from Figure 4 that the optimum ignition timing for this method of control, and also for the method discussed below in which the inlet-valve timing was varied, approximates, for the various compression ratios, the optimum ignition timing determined for the nondetonating fuel. The power obtained by throttling under these conditions approximates, at the higher ratios, that obtained for the fixed ignition timing of 30°. This would be expected, as the optimum timing determined with

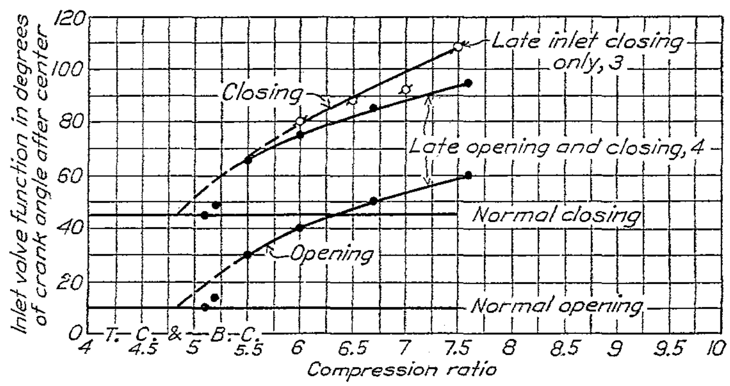

FIG. 5.—Inlet-valve timing used for conditions (3) and (4), Figure 4

this method varied but slightly from 30°. The permissible power output at a compression ratio of 7.3 is seen to be about 40 per cent less than obtained by maintaining full throttle and retarding the ignition. The indicated specific fuel consumption is, however, somewhat lower, although the variations in the quality of the fuel mixture have caused a scattering of the data and have thus obscured the advantage of the throttling method from this standpoint. It would be expected that the indicated fuel consumption with this method would be but little different from that obtained with the nondetonating fuel. This method would suffer somewhat by comparison on a brake basis owing to the higher friction losses with the engine throttled. It is worthy of note that the percentage decrease in indicated power is less than the percentage decrease in volumetric efficiency at the higher ratio. This method of control, although giving the best fuel consumption, gives the least power. The general trend of the power curves obtained with this method approximates that found by Ricardo (Reference 1, p. 94) when employing the throttling method to give no detonation with a fuel having detonation characteristics similar to gasoline, althought it is not stated in the reference whether a fixed ignition timing or a variable timing was employed.

Varying the inlet-valve timing has been employed in England in connection with the use of higher compression ratios in the Bristol Jupiter air-cooled engine. For this reason it seemed pertinent to investigate the relative performance to be obtained with this method of control. From Figure 4 it is seen that when the time of inlet opening and closing was varied simultaneously and the ignition maintained in the optimum position noted in the preceding discussion the permissible power output decreased with increase in compression ratio, the decrease at a compression ratio of 7.5 being about 29 per cent. Under these conditions there was considerable reversed flow through the inlet valve and, as a consequence, the fuel consumption with the single-cylinder engine increased considerably as the valve timing was varied from the normal. No account has been taken of the fuel that was deposited in the air heater as a result of the reversed air flow. Considerable improvement in fuel economy would be expected in a multi-cylinder engine, where several cylinders are connected to a common manifold. Some improvement in power and fuel consumption was obtained by maintaining the time of opening constant and varying only the time of closing, but the gain is not considerable and the method would not be practical for service use. The disadvantage of complexity more than offset the advantage of slightly better power obtained with this method as compared to the throttling method. Figure 5 shows the inlet-valve settings employed.

For all conditions, the heat loss to the cooling water in the head remained below 10.5 per cent of the total heat in the fuel; and for the cooling water in the cylinder barrel, below 7.5 per cent. When the variable valve timing was used, these losses were considerably reduced at the higher compression ratios.

Exhaust temperatures remained below 1,425° F. for all conditions of operation above 4.7 compression ratio. For the variable valve-timing method, these temperatures were likewise reduced considerably at the higher compression ratio.

A detailed discussion of the underlying conditions influencing detonation in these tests has been purposely omitted, as the data are not sufficiently precise to permit of making a detailed analysis.

CONCLUSIONS

From these comparative tests, it may be concluded that, of those methods investigated for controlling an overcompressed engine using gasoline under sea-level conditions, maximum power is obtained by maintaining full throttle and greatly retarding the ignition timing. Also, as the fuel consumption, exhaust temperatures, and heat loss to the cooling water are normal, and as this method of control is easily accomplished without adding to the complexity of the power plant, it may be considered the most practicable method for service use.

Throttling the carburetor with, approximately, full normal ignition advance gives the best economy of the various methods but the least power. Varying the timing of the inlet valve with, approximately full normal ignition advance gives somewhat greater power than obtained by the throttling method, but the fuel consumption is excessive, although the values for the latter given in this report are higher than would be obtained with a multi-cylinder engine.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *February 25, 1927*.

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